NOAA TM NESS 45

NOAA Technical Memorandum NESS 45

(Revision of NOAA TM NESS 36)

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite Service

A Technique for the Analysis and Forecasting of Tropical Cyclone Intensities From Satellite Pictures

VERNON F. DVORAK

WASHINGTON, D.C.

February 1973

National Environmental Satellite Service Series

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A TECHNIQUE FOR THE ANALYSIS AND FORECASTING OF TROPICAL CYCLONE INTENSITIES FROM SATELLITE PICTURES

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A TECHNIQUE FOR THE ANALYSIS AND FORECASTING OF TROPICAL CYCLONE INTENSITIES FROM SATELLITE PICTURES

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ABSTRACT. A technique for using satellite pictures to analyze tropical cyclones is described in detail. Specific instructions are given for detecting changes in cyclone intensity, for estimating the magnitude of the intensity, and for forecasting 24-hour intensity changes. A code for transmitting this information is also described.

1. INTRODUCTION

Since early in the meteorological satellite program, tropical cyclones in all stages of development have been seen in satellite photographs. Methods were developed for estimating cyclone intensities by noting various cloud features associated with the cyclones. A new approach to relating cloud features to the current and future intensities of tropical cyclones is described herein.

This technique provides the analyst with a systematic procedure in which the interpretation of satellite imagery is combined with a model of tropical cyclone development.

The model describes cyclone development and dissipation as a day-to-day progression through recognizable combinations of cloud characteristics, or classes. The analysis of the progression is made in relation to the observed change from a previous picture within limits set by the model. The model also accounts for observed differences in the wind speeds of developing and weakening storms showing similar cloud characteristics.

The cloud characteristics that define the classes are described as either central features or banding features. These cloud features emphasize the significance of the amount and form of the dense overcast clouds associated with the disturbance center. The classification principles apply to "cold" as well as "warm" type developments and consequently may be used in the analysis of "semitropical" disturbances. Although the technique makes use of all available data and skill, it can, when necessary, be used with simple judgments on the most obvious features visible in picture data.

Another set of cloud characteristics is used in the technique to improve the forecasting skill of the model. These features appear to be related to the inflow, outflow, and vertical motions of the disturbance at picture time.

2. THE TECHNIQUE

The technique is described in four parts: A. Rules for analysis and forecasting, B. Chart for determining the preliminary T-number, C. Indications of change, and D. Definitions and training aids.

A. Rules for Analysis and Forecasting

The object of the technique is to answer systematically five questions about the disturbance, using satellite pictures. Questions 1 through 4 concern the past change, the current state, and the ongoing change of the disturbance and are answered in code form as illustrated in figure 1. Question number 5 is answered implicitly from the combination of symbols in the code.

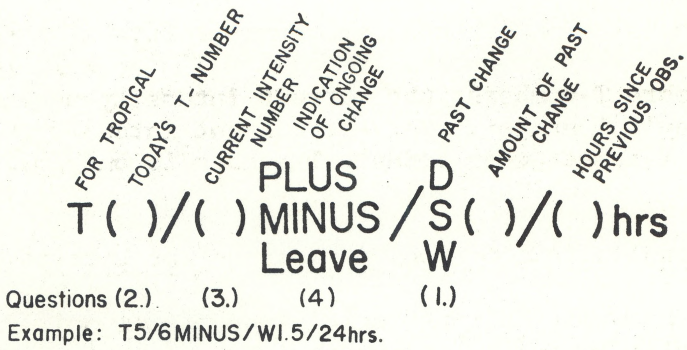


Figure 1. -- The code form used to describe the disturbance and its development.

The five questions and the rules that determine the answers are listed below. The questions must be answered in the following order:

1. <u>How has the disturbance changed since the previous observation</u>?

Compare the current picture with the picture from the previous observation. Has it developed (D), remained the same (S), or weakened (W)? This judgment is made solely in terms of the principles of the technique listed in part C.1., page 6. (Encode as D, S, or W.)

2. <u>Which T-number best describes the disturbance</u>? (For definition of T-number, see D.12., page 13.)

a. Determine the T-number that is expected from model considerations alone. Use yesterday's T-number and the answer to question 1. in conjunction with the table of par. 5.a., page 4. For this purpose use the captions in the table which are enclosed in parentheses.

b. Next, use the chart of part B on page 5 to determine the preliminary T-number from today's data. Note that CF plus BF equals preliminary T-number.

c. The final determination of today's T-number is then made by adjusting the preliminary T-number of b. (data) to the expected T-number of a. (model) as close as the data will allow. Model constraint: The final T-number must be within one T-number of the model expectation. (Encode to the nearest 0.5 T value.)

d. After the T-number has been decided on, fill in the amount of past change in T-numbers.

3. What is the current intensity (C.I.) number? (A number related to the cyclone's maximum windspeed and its minimum sea level pressure. See part D.6., page 10.)

a. If D or S is used in the code, the current intensity number will be the same as the T-number.

b. If a W is used in the code, the current intensity number will usually be greater than the T-number. If today's T-number is smaller than yesterday's by 1 or more T-numbers, the current intensity number will be one greater than today's T-number. Set the current intensity number 0.5 greater than today's T-number when today's T-number is only 0.5 lower than yesterday's.

4. What are the indications of "ongoing change" at picture time?

A disturbance will normally exhibit indications of intensification or weakening in the satellite imagery as it develops or weakens. These indications are listed in part C.2., page 6.

a. A PLUS or MINUS may be added to the code only when the dominant signs of ongoing change conflict with the amount or trend of the past change indicated in the code.

b. A PLUS may be added to the code when:

1) A "W" or "S" is encoded but indications of ongoing intensification are clear. (A PLUS is normally necessary when a disturbance has experienced temporary weakening while passing through an unfavorable environment such as a land area or a region of strong vertical sheer.)

2) Indications of ongoing intensification are strong and the "averaged" development over the past 48 hours has exceeded the "modeled" rate of development. (See page 4.)

c. A MINUS may be used in the code when:

1) A "D" or "S" is used in the code but indications of ongoing weakening are clear. (A MINUS is necessary to modify the forecast when a disturbance is entering an unfavorable environment and/or has attained its maximum development.) The conditions under which the analyst must be alert to the possible use of a MINUS are listed in C.2.b, page 7.

2) Indications of weakening are clear and the "averaged" weakening over the past 48 hours has exceeded the "modeled" rate of change.

5. What is the 24-hour intensity forecast? (Applicable only when the system center does not pass over land during the forecast period.)

a. When neither a PLUS nor a MINUS is coded, the 24-hour forecast is shown in the table below. This table is also used for determining today's "model" T-number by using the captions in parentheses.

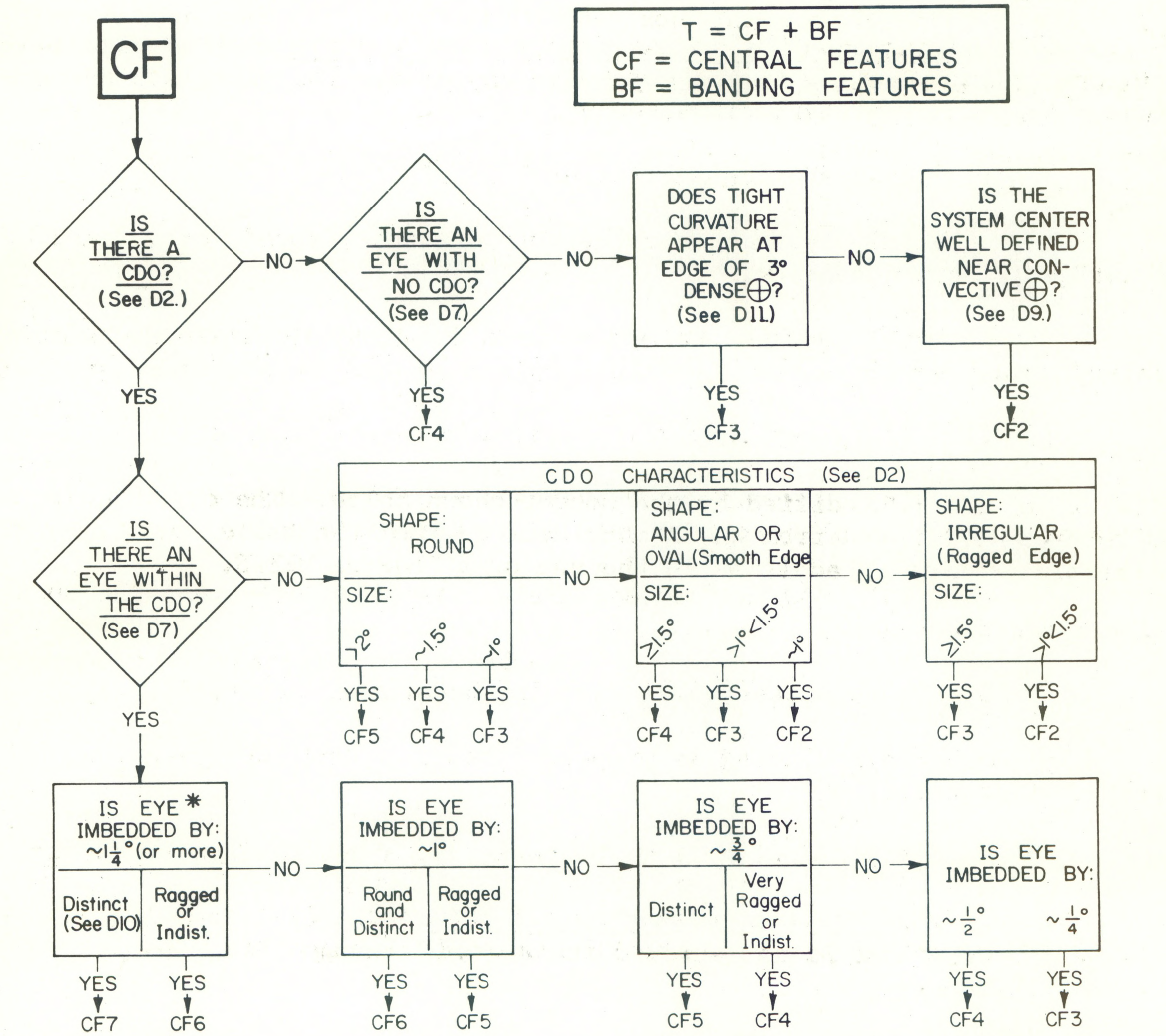
Current intensity number (Yesterday's T-number)	1	(1.5)	2	3	4	5	(5.5)	6	(6.5)	7	8
	24-Hour Forecast C.I. Number (Today's "model" T-no.)										
D	1.5	(2)	3	4	5	6	(6)	6.5	(6.5)	7	8
S	1	(1.5)	2	3	4	5	(5.5)	6	(6.0)	6.5	7
W	1	(1)	1	2	3	4	(4.5)	5	(5.5)	6	7

b. When a PLUS or MINUS is coded, the "modeled" forecast in the table above will be modified by the amount shown below. The quantity to be added to or subtracted from the number derived from the table above depends on the past change in addition to the use of a PLUS or MINUS.

Symbols in the code	Amount to be added or subtracted
+ D	+ 0.5
+ S	+ 0.5
+ W	+ 1.0
- D	- 1.0
- S	- 0.5
- W	- 0.5

c. This item is not entered in the code message.

B. **Chart for Determining the Preliminary T-Number.
(See page 15 for examples.)**



BF = A NUMBER RELATED TO THE AMOUNT OF DENSE OVERCAST IN BAND FORM THAT CURVES EVENLY AROUND THE CENTRAL FEATURE WITHIN 4° OF THE SYSTEM CENTER (See D1.)

BF = 0 when little or no quasi-circular banding is apparent.

BF = 1 when a $\frac{1}{2}°$ wide band completely encircles the central feature, or when a 1°, or wider, band encircles more than $\frac{1}{2}$ the central feature.

BF = 2 when a $\frac{1}{2}°$ wide band is coiled twice around the central feature, or when a 1°, or wider, band is coiled once around the central feature.

When the above conditions are not quite met, values of $\frac{1}{2}$ or $1\frac{1}{2}$ may be used.

*See "Large Eye" limits in D7, page 11.

C. Indications of Change

1. Past Change. (Disturbance change since the previous observation.)

a. Indications that intensification has occurred. (See page 14 for illustrations.) Use a D in the code when any of the following has occurred without compensating signs of weakening.

1) If system center (or eye) is visible,

(a) System center is more distinct, round, or defined by more tightly curved banding.

(b) More dense overcast is observed closer to the system center, or the system center is more deeply imbedded* in the overcast.

2) If system center is covered by dense overcast,

(a) Central dense overcast (CDO)* shape has changed from irregular to more angular or from angular to more rounded.

(b) CDO has become larger. (Applies only when the CDO shape has not changed.)

3) If overcast quasi-circular banding is observed,

(a) Banding is wrapped farther around the system center in more or wider coils.

(b) Banding is more concentric about the system center.

b. Indications that weakening has occurred. (See examples on page 19.) Use a W in the code when the observed changes are opposite to those listed above.

c. Indications that no change has occurred. Use an S in the code when little change is evident, or when the signs of intensification and weakening are approximately balanced.

2. Ongoing change. (Disturbance activity at picture time.)

a. Indications of ongoing intensification. These inferences concern the probable strength of the (1) low level inflow, (2) upper level (multi-directional) outflow, and (3) the vertical motions apparent in the disturbance at picture time. Number (4) describes the overall cloud pattern.

1) Convective feeder bands* spiral into the central feature. The "strength" of these bands is greater when the alignment of the cumulus elements is more distinct, the amount of dense overcast in the bands is greater, the boundaries of the overcast bands are more abrupt, and the angle at which the bands approach the central feature is greater. (See part D.5.)

*See part D

2) Cirrus gives the disturbance a fuzzy appearance away from the central feature in three or more quadrants or appears in anticyclonically curved bands.

3) The CDO is bright or solid looking with an abrupt boundary in at least one quadrant. An exception to this rule is discussed in b.2) below.

4) The overall cloud pattern is more comma-shaped than circular usually having mostly overcast convective cloudiness equatorward or east of the system.

b. Indications of ongoing weakening. These inferences concern the probable weakness of (1) low level inflow, (2) upper level (multidirectional) outflow, and (3) upward vertical motions.

1) Convective feeder bands are either not apparent, indicate little active convective cloudiness, or curve evenly around the CF. If bands are apparent, they will appear gray or thin or ragged, or they will curve around the CF rather than into it.

2) Cirrus appears grayish with little anti-cyclonic pattern. Also, if the cirrus appears to be blowing off the disturbance in one direction, conditions are unfavorable for development. That is, if the clouds display sharp edges on one side of the disturbance with fuzzy edges on the opposite side, upper level flow across the system is indicated.

3) The central features display little dense (bright or solid looking) cirrus near the disturbance center. Banding, breaks or cellular clouds appear around the system center where more solid clouds were observed previously.

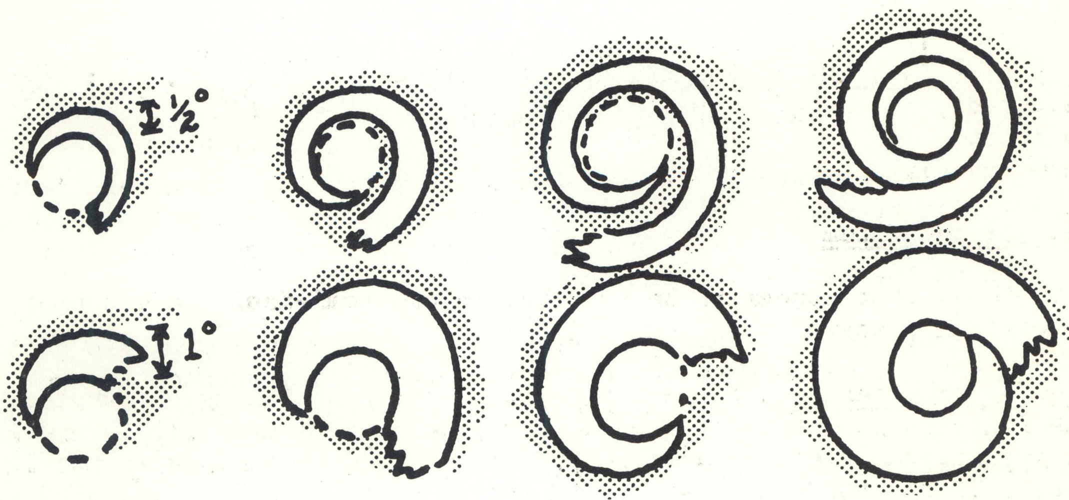
4) The overall cloud pattern is circular and isolated from active convective cloudiness. (This is especially significant in "peaking" storms at T 4.5 or greater.)

The analyst must be alert to the possible use of a MINUS under the following circumstances. a) When a developing cyclone is near the expected "peak" intensity. (The "peak" is expected to occur approximately four days after the T2 was observed.) At this time the isolation of the cloud pattern as mentioned in 4) above is sometime the only indication that the cyclone has stopped developing. b) When the disturbance is entering an area of strong flow aloft which is blowing the cirrus unidirectionally across the disturbance center. (The disturbance usually appears "blocked" with its cloud pattern elongated perpendicular to it's direction of motion. c) When recurvature is evident with a near poleward direction of motion. d) When the disturbance has entered a stratocumulus region and the stratoform clouds appear adjacent to the convective clouds of the disturbance. e) When a disturbance is on the verge of crossing a sizeable land feature such as Luzon or Yucatan. (See page 19 for examples of weakening storms.)

D. Definitions and Training Aids

1. Banding Features (BF)

a. Quasi-circular bands. (Related to current intensity.) Bands of various widths that encircle the system center to varying degrees give a BF value of 0.5 to 2 as illustrated below. When the amount of "quasi-circular" overcast banding is less than the BF = 1/2 example use BF = 0. Bands not to be considered as BF are: those that define the system center, and those less than 1/2° from the center or more than 4° from the center.

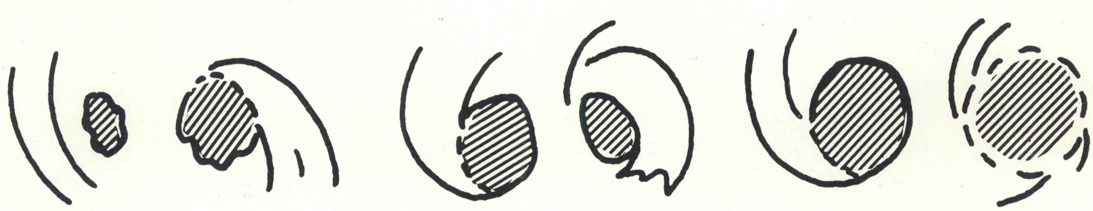


BF = 1/2 BF = 1 BF = 1 1/2 BF = 2

2. Central Dense Overcast (CDO)

A dense, solid looking mass of clouds covering the focal point of the banding or surrounding the eye. The CDO is defined only when the system center is defined under or within a dense overcast.

a. The CDO shape is a valuable clue for estimating intensities when an eye is either not visible or appears indistinct. The CDO shape in a developing cyclone usually changes from irregular to angular, or oval, to round as shown below.



IRREGULAR ANGULAR OR OVAL ROUND

b. The CDO size is also important to intensity estimates when an eye is not visible (or indistinct). See part B. Two crucial sizes are the 1.5°-diameter irregular CDO defining the CF3 and the greater-than-2° diameter round CDO that defines the CF5.

c. The CDO boundary. During development, the CDO boundary is usually well defined with an abrupt edge in at least one quadrant of the cloud mass. The remainder of the boundary follows the curve of the wedge-shaped cloud minimum around the less well defined portion of the cloud mass. As a cyclone develops, the boundary usually changes from ragged and uneven to smooth and well defined. When development stops, the boundary becomes fuzzy and poorly defined.

d. The CDO texture may appear lumpy during the initial stages of development, but when the imbedded distance of an eye is being considered, only smooth, even textured cirrus defines the CDO. (A round wall cloud shadow may also be included.)

3. Cloud System

All clouds that appear to be involved in one semi-isolated grouping or in one vortical pattern.

Cloud system center: The eye or vortex center of the system when one of these features is visible. When two or more centers are visible within the same system, the system center is the one defined by banding in the lower clouds. If the two patterns are similar in appearance in terms of C.2.a., the more westward one is considered the system center. When no eye or vortex is visible, the center will be defined as the focal point of all system banding or the geometric center of the cloud system, as appropriate.

4. Common Developmental Patterns. Illustrated on p. 14.

5. Convective Feeder Bands

Cumuliform bands that curve into the cloud system at cross-angles. Examples of this type of banding are illustrated in D.2.a. These bands are related to ongoing intensification and do not affect the T-number determination.

6. Current Intensity Number

The following table relates the current intensity (C.I.) number to both the maximum sustained wind speed (MWS) and the minimum sea level pressure (MSLP) of the disturbance. The relationships were determined empirically with most of the data taken from the North Pacific region. A significant difference in the C.I.-pressure relationship was observed between the Atlantic and Pacific Ocean areas requiring that they be listed separately.

C.I. Number	MWS (Knots)	MSLP (Atlantic)	MSLP (Pacific)
1.5	25K	1010 mb	1004 mb
2	30K	1007 mb	1001 mb
2.5	35K	1003 mb	997 mb
3	40K	998 mb	992 mb
3.5	50K	993 mb	987 mb
4	60K	988 mb	982 mb
4.5	72K	979 mb	973 mb
5	85K	970 mb	964 mb
5.5	97K	960 mb	954 mb
6	110K	948 mb	942 mb
6.5	122K	934 mb	928 mb
7	135K	920 mb	914 mb
7.5	150K	906 mb	900 mb
8	170K	891 mb	885 mb

(The MWS for C.I.1 depends on the type of disturbance observed.)

The current intensity number is held higher than the T-number when the appearance of a cloud system indicates it has weakened by one-half or more T-numbers during the past 24 hours. This rule follows from the observation that the wind speed reduction in a weakening storm occurs about 24 hours after the degeneration of the cloud characteristics indicate this weakening. One problem with the system in this regard is the case where a storm generates its maximum winds approximately halfway between 24-hour observations. When this occurs the analyst will see a "healthy" storm at one observation time and will forecast a "modeled" increase. The succeeding observation, however, will indicate either S or W, but the wind speed will actually be one-half C.I. number higher than on the previous day. This "peaking" of a disturbance between observations should be understood by the analyst so he can bias the classification on the high side when it occurs.

The isotach pattern associated with the maximum wind speeds listed above appears to be related to the overcast quasi-circular bands, the CDO, and the eye with no CDO. The 40K isotach normally encloses the outer limits of all of these features. The dense overcast "feeder bands" are usually enclosed within the 30K isotach.

7. Eye

a. An eye is defined in a satellite picture as either:

1) A break within a CDO. (The CF is determined by the character of the eye and the distance of the eye to the nearest boundary of the CDO.)

2) A circular break with no CDO, defined by one overcast band that wraps evenly around a break on the edge of a 3° (or larger) dense cloud mass. The clouds comprising this band may appear to be at middle levels (grayish, not solid) or cumuliform. The CF number for this type of eye will usually be CF4 but when the band is dense overcast and wraps completely around the eye CF4.5 is indicated.

The technique places two requirements on the above definitions:

a) Eye must appear at focal point of all system banding.
b) Eye is not defined unless the disturbance was a T2 or greater 24 hours or more before the observation of the eye.

CF3 CF3 CF3 CF4 CF4.5

Pre-Eye Types "Eyes" without CDO

CF4 CF5 CF5 CF6 CF6

Imbedded-Eye Types

b. Large eyes of three-fourths degree diameter or more limit the T-number of the storm as follows:
1) A large, ragged eye storm is limited to T5 or less.
2) A large, round eye storm is limited to T6 or less.

c. Imbedded distance of the eye: The shortest distance from the innerwall of the eye to the nearest banding break or shadow, or to the closest boundary of the CDO. Normally this would be across smooth textured cirrus but a round wall cloud shadow within the CDO may be included. The analyst should measure from the center of the eye outward for small eyes of about one-fourth degree diameter or smaller.

8. Focal Point of Banding

The area or point that two or more curved cloud bands merge to, spiral toward, hook at, or curl around. Also defined as the one point of mergence or implied center of curvature of all the system's banding.

9. Seedling Development

The initiation of development is visible in cloud features as a combination of convective banding (inflow) characteristics, cirrus (outflow) characteristics, and the amount of dense overcast near the center. Development (T2) is indicated when combinations of these features are favorable (a) or when one or the other appears very pronounced (b).

a. A convective cloud system of overcast cumulus and/or cirrus at least 3^{o} latitude in extent which contains:

1) Curved convective cloud bands of well-aligned elements that merge to, spiral toward, hook at, or curve around one small area ($<1.5^{o}$ in diameter) near to or within the overcast. T2 is also indicated when the system center is defined within 1.5^{o} latitude but not under the edge of a dense overcast.

2) Cirrus indicating that the upper level flow is either very weak or anticyclonic over the central feature. If the appearance of the cirrus implies straight line flow from one direction over the system center, conditions are unfavorable for development. When this condition is observed and a "D" is used in the code, the analyst should be especially alert to the possible use of a "MINUS" for disturbance of T1, T1.5 and T2 strength.

b. If either strong convective feeder bands as described in part C.2.a. (strong inflow) or a well defined anticyclone (strong outflow) is indicated, the requirement of banding alignment or a small area of mergence may be relaxed. The appearance of dense overcast cloud mass nearly 1^{o} latitude in diameter near the system center may also be used to relax these requirements.

When a disturbance is observed during the tropical season that does not meet the criteria of a T2 or greater, use T1 or T1.5.

Seedling development is normally slow at high latitudes, where a land mass appears equatorward of a disturbance, and for early season storms. Under these circumstances development should be very clearly indicated before T2 is used.

During seedling development, weak disturbances sometimes undergo minor intensity fluctuations before a constant rate of development begins. Because of this the analyst should avoid the use of a "W" for T1.5 and T2 disturbance unless both past change and ongoing change clearly indicate weakening. When the analyst is in doubt an "S" should be used.

10. Superstorm Indicators

The T7 or T8 class of storm will appear 24 hours after the appearance of a vigorous T5 or T6 class storm. The superstorm will reveal itself in the expansion of its CDO or increased band coiling or a combination of both. Good indicators of the superstorm which at times occur simultaneously with these properties are:

a. A wide smooth-textured band which completely encircles a very round CDO containing a well-centered, distinct, round eye.

b. Appearance of an eye within an eye. It appears as though you are looking down inside one wall cloud and are seeing a second, smaller one at a lower level.

c. A spiral, broken, or elongated wall cloud. These always appear in very distinct eyes. They should be considered significant only when a vigorous T5 or T6 classification has been observed previously.

11. Tight Curvature

Bands with a radius of curvature of one-half degree latitude or less. For T3 this curvature must appear at, or under, the edge of a dense cloud mass at least 3^{o} in general diameter. When the overcast contains quasi-circular banding, the 3^{o} overcast requirement may be relaxed. (See pre-eye types, part D7.)

12. T-number

The T-number, which may range from T1 to T8, is a description of a tropical disturbance in terms of cloud characteristics visible in satellite data. The T-number is arrived at by a systematic blending of data with a model of tropical development according to the rules outlined in part A., 1 and 2. The T-number is not used for intensity estimates since the wind speed may differ in developing and weakening storms showing similar cloud characteristics. (See C.I. number,A.3., page 3.)

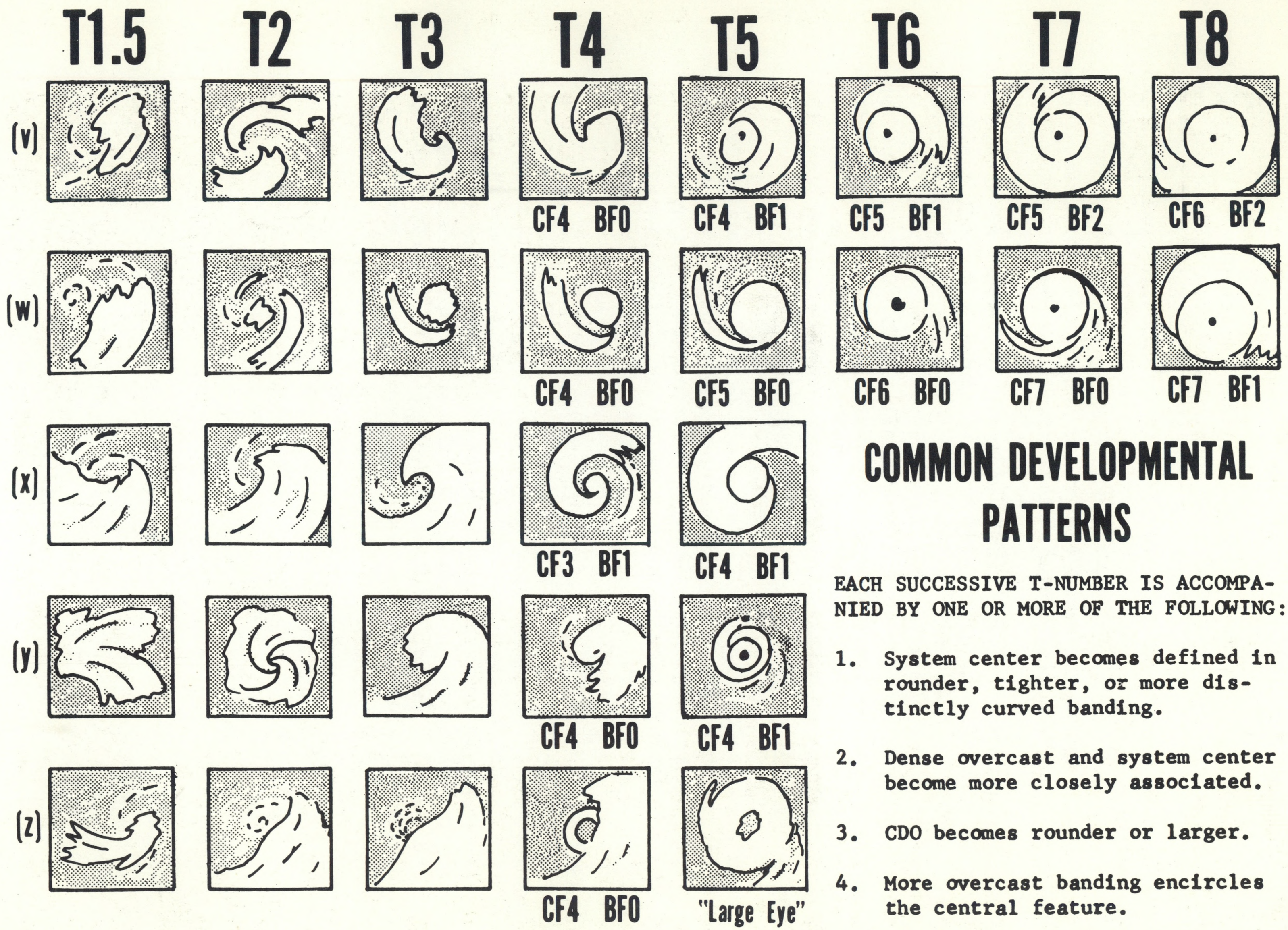


Figure 2. -- Common developmental patterns.

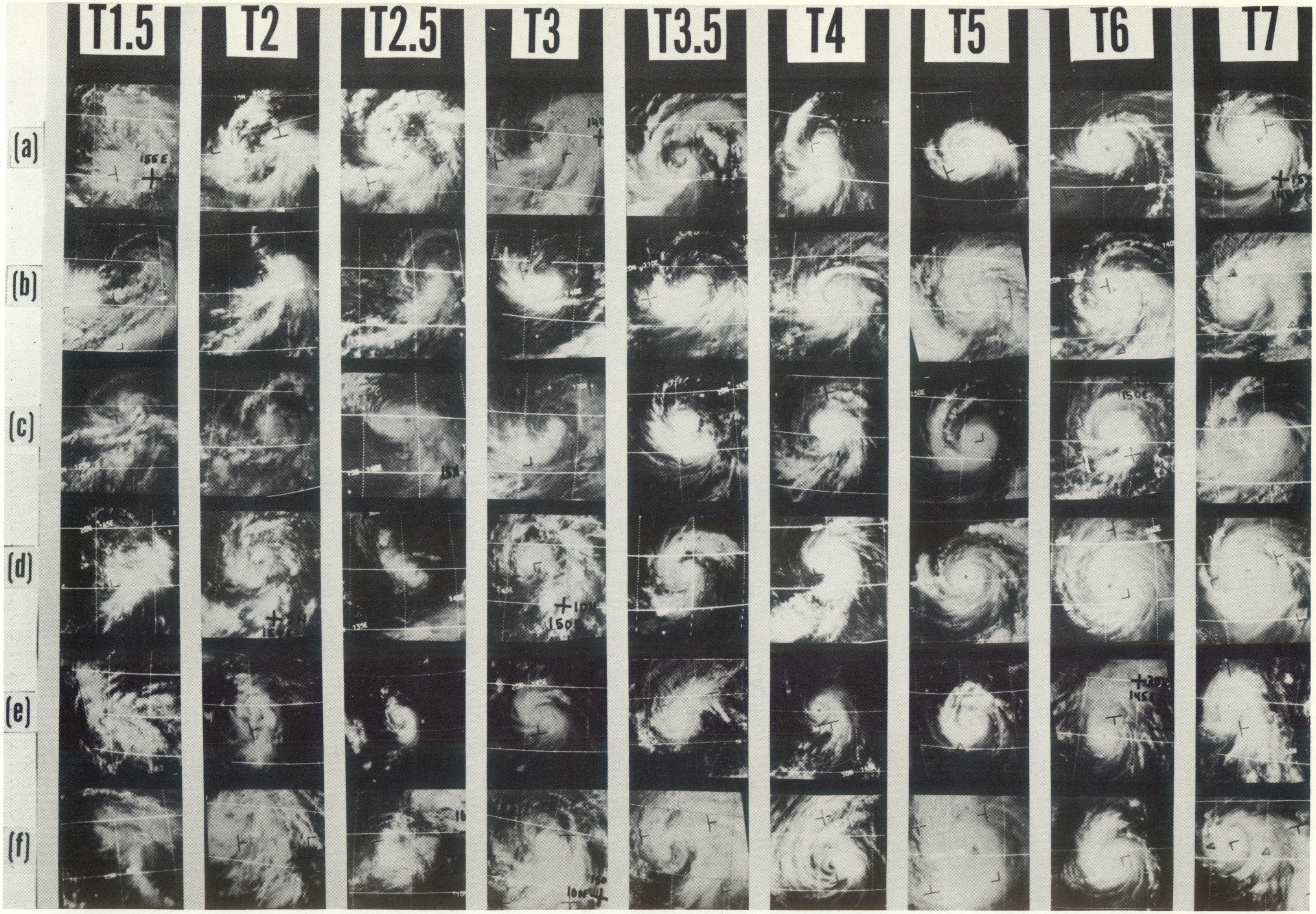


Figure 3. -- Examples of preliminary T-number patterns.

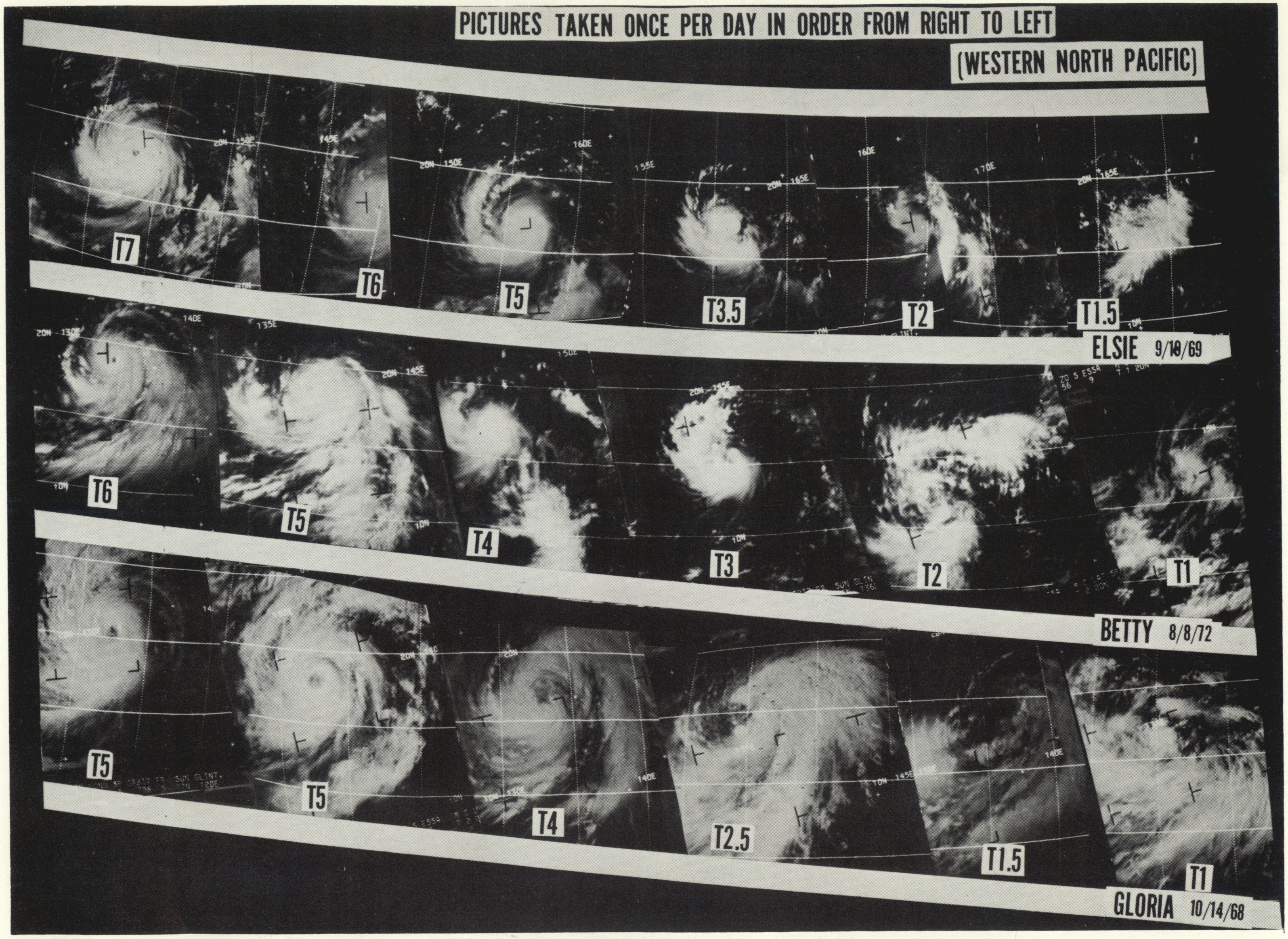


Figure 4. -- Types of tropical development (western North Pacific).

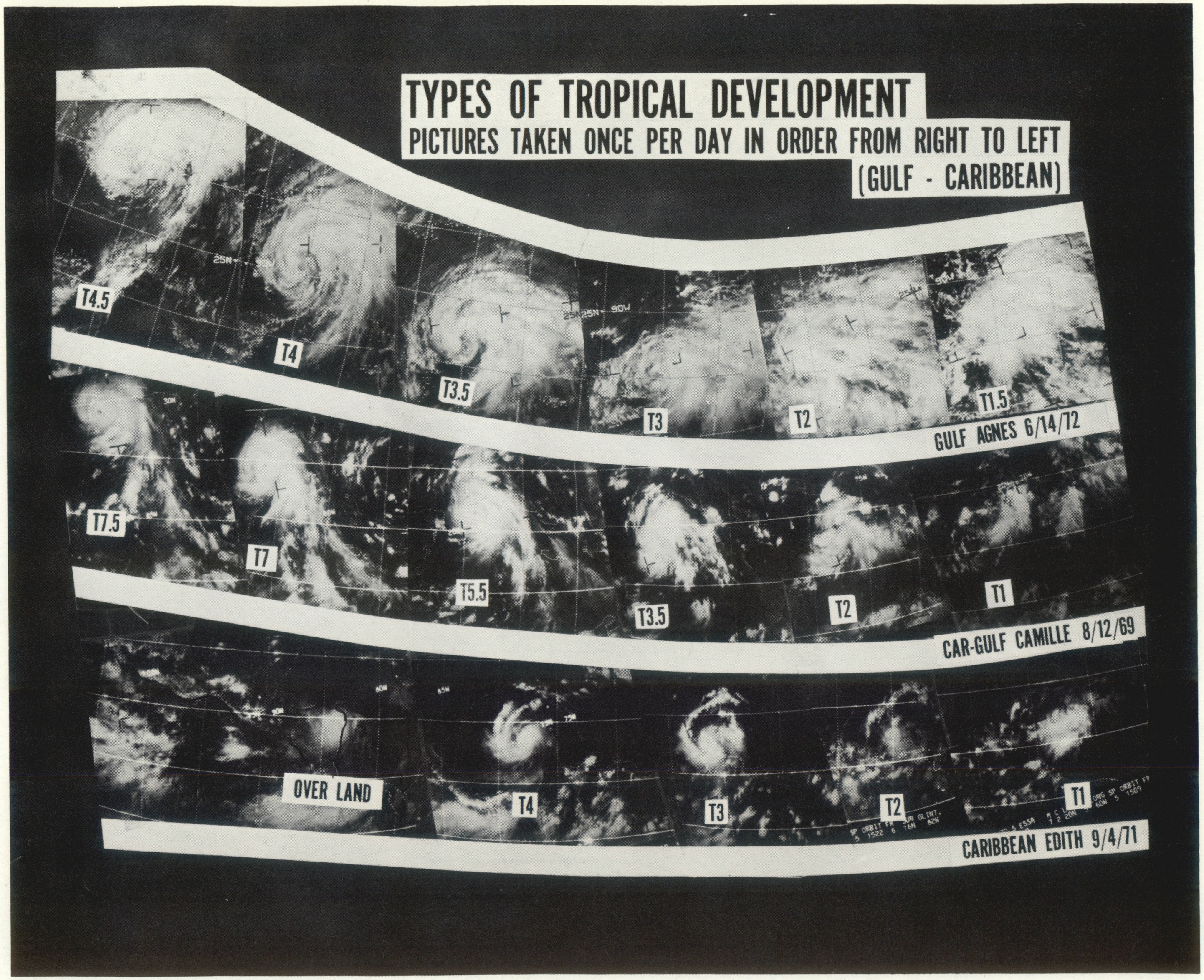


Figure 5. -- Types of tropical development (Gulf - Caribbean).

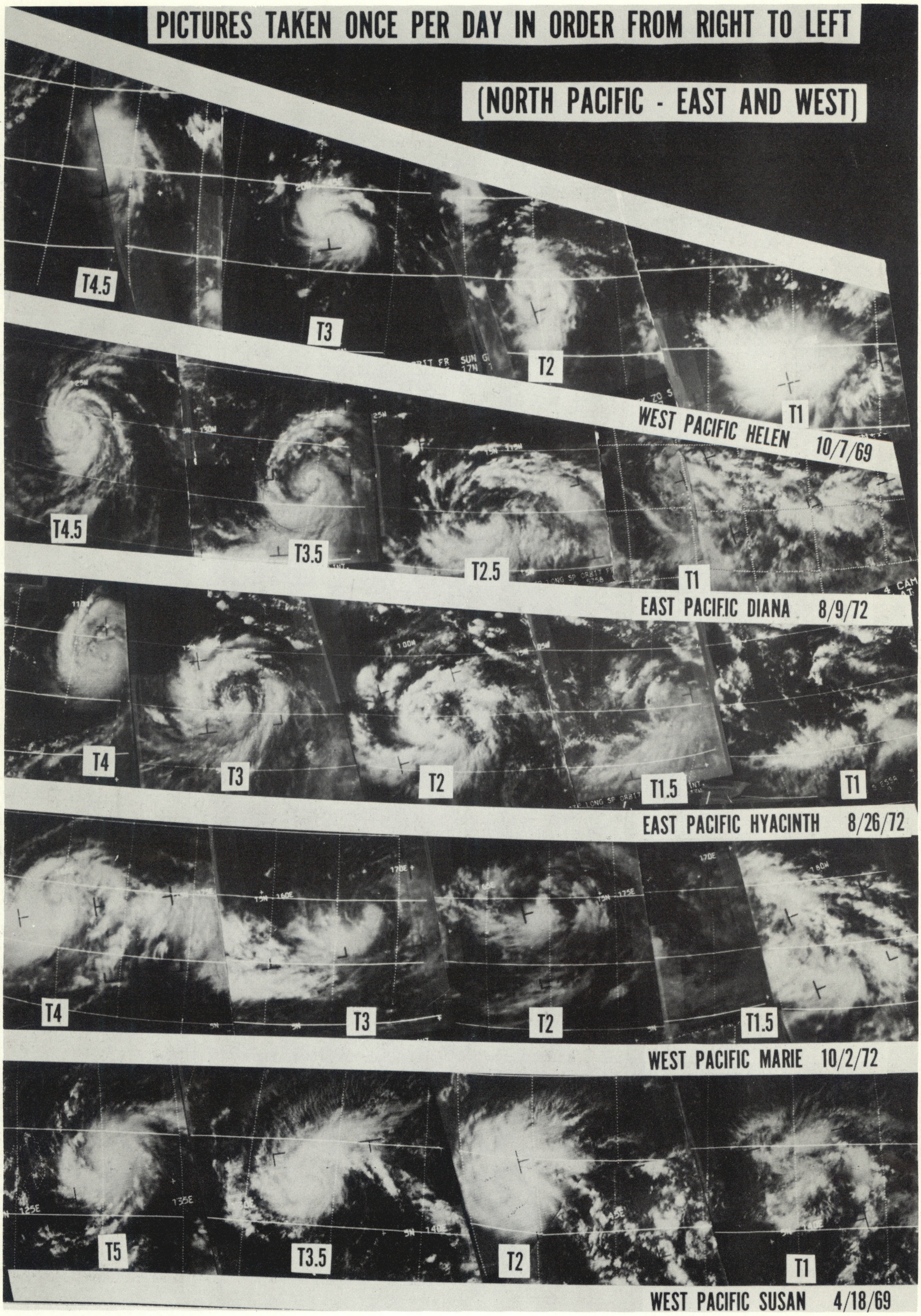


Figure 6. -- Types of tropical development (North Pacific - east and west).

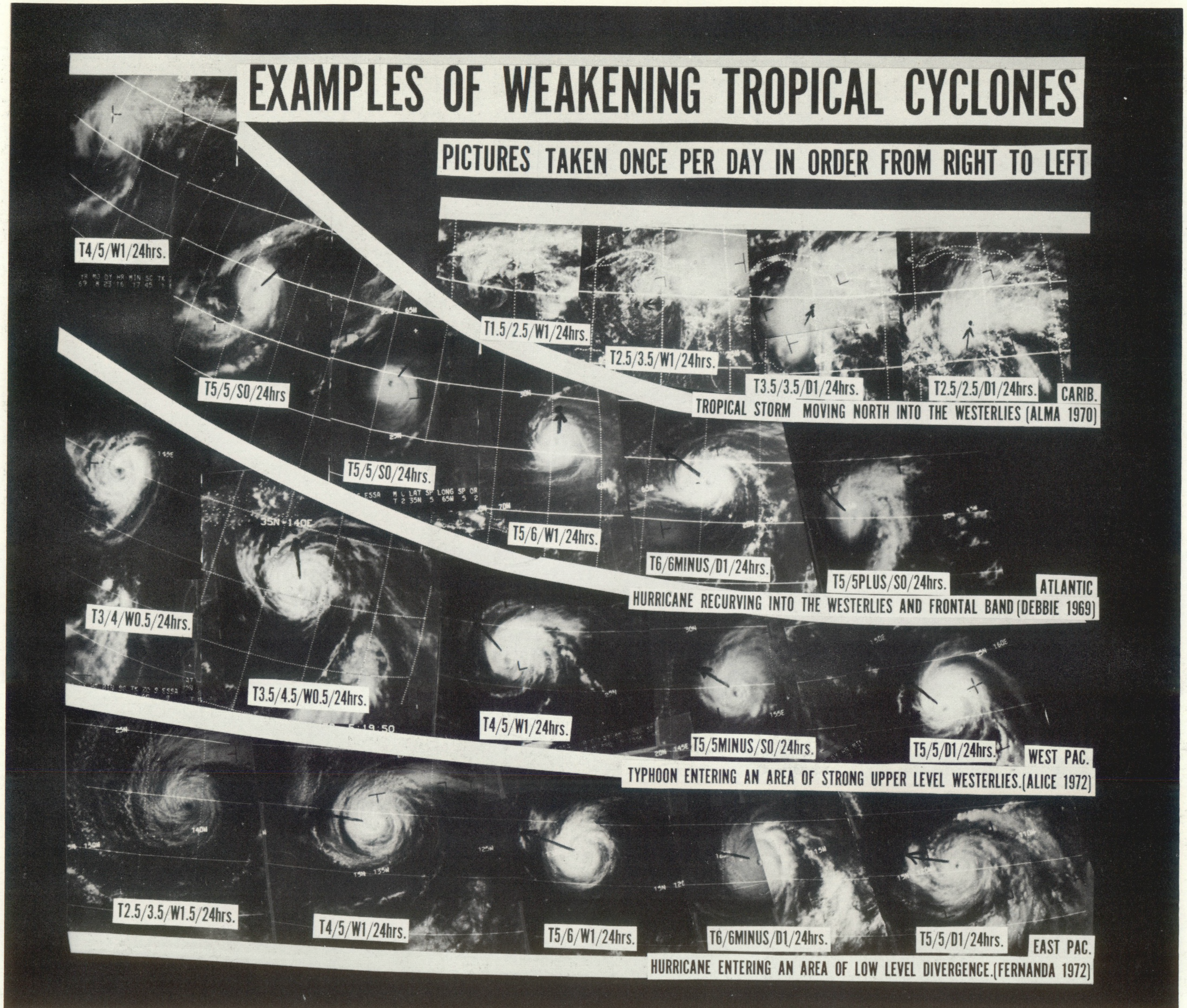


Figure 7. -- Examples of weakening tropical cyclones.

(Continued from inside front cover)

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